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Efficacy of tank mixture glufosinate ammonium and indaziflam for weed control in oil palm

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ABSTRACT
The apprehension among oil palm farmers on the toxicity of glyphosate necessitated the need for an alternative herbicide for weed control in oil palm. Thus, a study was conducted at the Nigerian Institute for Oil Palm Research (NIFOR) to determine the efficacy of tank mixture of glufosinate ammonium (Basta) + indaziflam (Alion) for weed control in oil palm. The treatments consisted of glyphosate at 1.5 kg a.i ha^{-1}, glyphosate + diuron at 1.5+2.0 kg a.i. ha^{-1}, glufosinate ammonium at 0.4 kg a.i. ha^{-1}, glufosinate ammonium at 0.5 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.5 + 0.04 kg a.i. ha^{-1}and weedy control. The results showed that tank mixture of glyphosate + diuron at 1.5 + 2 kg a.i ha^{-1}, glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1} and glufosinate ammonium + indaziflam at 0.5 + 0.04 had the best weed control efficiency of 78.5%, 78.6% and 78.3% respectively up to 20 weeks. The study concluded that tank mixtures of glufosinate ammonium + indaziflam were as good as glyphosate + diuron for weed control in oil palm.

Keywords: oil palm; weed; efficacy; herbicide; weed flora
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Introduction

Manual weeding has constituted a serious weed control problem in oil palm because of the required labour for the frequent slashing of the luxuriant weed growth within the wide inter-row spacing in oil palm production. The scarcity of labour and the huge cost involved in weeding the inter-rows and circles around the palms has made some small-scale oil palm farmers abandon their plantations. Planting cover crops to suppress weeds could have been better; however, the high cost of procuring and establishment of cover crops is beyond the reach of most small-scale farmers (Ekhator *et al.*, 2020).

Therefore, chemical weed control which has been the alternate practice among small-scale farmers and large-scale oil palm growers becomes imperative. In effect, this has reduced the dependence on labour for hand weeding which often delays operations in times of scarcity (Hornus, 1990). Manual weeding which is often practiced among small-scale oil palm farmers can be more expensive than chemical weeding (Hamel, 1986). Thus, chemical weeding is considered a suitable alternative for weed management especially in large-scale oil palm plantations (Ekhator *et al*., 2018a).

Glyphosate provides control of broad spectrum of weeds in oil palm fields (Ikuenobe, 1992). Tank mixture of glyphosate + metsulforon has been shown to be effective for annual and perennial weed control in the oil palm (Ekhator *et al*., 2018a). Other herbicides, such as Folar (glyphosate + terbuthylazine), glyphosate + indaziflam, Velpar k4 (Hexazinone), triclopyr, and triclopyr + asulam have also been found suitable for weed control in oil palm (Ekhator *et al*., 2020; NIFOR, 2003; Boum & Hornus, 1987; Queneez & Dufor, 1982a).

The apprehension among farmers on the toxicity of glyphosate for weed control in oil palm especially at the juvenile stage of field establishment has necessitated the need for a friendly herbicide for oil palm production.

Glufosinate ammonium (Basta) is a partial systemic post-emergence herbicide used in the control of both annual and perennial weeds in plantation crops (Akobundu, 1987); while indaziflam (Alion) is a systemic herbicide for selective pre-emergence control against broadleaves weeds and some grasses in plantation crops (Ekhator *et al*., 2020). The long soil residual activity of indaziflam could provide long-term weed control when in mixture with other post-emergence herbicides (Ekhator*et al.,* 2020). Herbicide could reduce application cost and herbicide resistance of weeds (Diggle *et al*., 2003; Lich *et al*., 1997). Tank mixtures of herbicides broaden the spectrum of weed species control and provide good control at considerably lower dosages than dosages utilized in single applications (Ekhator *et al*., 2018a). Glufosinate ammonium (Basta) and indaziflam (Alion) are newly formulated products of Bayer Crop Science West and Central Africa and were sponsored in NIFOR for evaluation on weed control in oil palm.

The objective of this study was to evaluate the effect of glufosinate ammonium and indaziflam along with glyphosate and diuron commonly used for weed control in oil palm.

Materials and Methods

The experiment with seven treatments was laid out in a randomized complete block design in three replicates in field 30 at the Nigerian Institute for Oil palm Research (NIFOR), Benin City, Nigeria. The total plot and experimental unit size adopted were 16,200 m^2 (406 m x 45 m) and 144 m^2 (36 m x 4 m) respectively. The palms in field 30 were planted in May, 2015 and were one year and three months old at the commencement of the trial in July, 2016. The palms were planted in a standard spacing of 9 m x 9 m in triangular (NIFOR, 2003). Four meter-wide strips of palm rows were applied with the appropriate herbicide treatments. The treatments consisted of glyphosate at 1.5 kg a.i ha^{-1} (as reference single herbicide), glyphosate + diuron at 1.5+2.0 kg a.i. ha^{-1} (as reference tank-mixed herbicide), glufosinate ammonium at 0.4 kg a.i. ha^{-1}, glufosinate ammonium at 0.5 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.5 + 0.04 kg a.i. ha^{-1}and weedy plot (non-treated plot reference). These were applied post-emergence to actively re-growing weeds slashed four weeks prior to herbicide application. Herbicides were applied using a manually mounted 15 liters knapsack sprayer fitted with a hand-held operated nozzle and calibrated to deliver a spray volume of 240 liters per hectare. The herbicides were applied in the morning during warm temperatures and high humidity. Data recorded monthly were predominant weed flora, visual assessment of weed control, biomass of weed growth, weed control efficiency, and weed coverage and herbicide toxicity. Weed control efficacy in the treated plots was interpreted according to the scale of the European Weeds Research Council (EWRC) (Marnotte & Tehia, 1992; Mathieu & Marnotte, 2000; Auskalnis, 2003; Ekhator *et al*., 2018a). European Weed Research Society Scale (EWRS) was used to interpret herbicide toxicity. Results interpreted were reference to the two scales. The tables are presented in appendixes i and ii.

Weed dry (biomass) weight

The weed shoot falling within the frames of the quadrat of size 1 m × 1 m were harvested from the ground level after throwing the quadrat randomly within each experimental plot four times. Then, the mean weed dry weight of the quadrats was recorded after oven-dried to a constant weight at 80°C for 72 hours.

Visual weed control rating

Visual weed control rating was taken by using the weedy plot as reference. Then visual assessment of the percentage reduction of weeds in the treatment plots was compared to the weedy plot.

Weed control efficiency

Weed control efficiency was calculated as per the procedure

$$WCE\% = \frac{WD_C - WD_T}{WD_C} X\ 100$$

Where WCE Represents weed control efficiency (percent)

WD_C Represents weed biomass (kg·m^{-2}) in control (weedy) plot

WD_T Represents weed biomass (kg·m^{-2}) in treated plot (Ofosu-Budu *et al*., 2014, Ekhator *et al*., 2018a). Weed coverage: Weed coverage was assessed by visual estimation of the percentage coverage of the emerged weeds in the treated plot within the 1 m × 1 m quadrat against the weedy plot as explained by EWRC for herbicide evaluation (Ekhator *et al*., 2018a).

Herbicide toxicity

Plant toxicity due to herbicide was assessed by comparison of the state of palm tree fronds in the treatment plots with area without herbicide treatment at the slashed inter-rows borders lines. The toxicity rating was assessed using EWRS –scale for visual rating of herbicide toxicity

Statistical Analysis

The data on weeds were statistically analyzed using the analysis of variance in Gen Stat Version 8.1 (2005). Where significant differences existed, the critical difference was constructed at a five percent probability level for guidance. However, interpretation of results was largely based on EWRC scale for herbicide evaluation and EWRS – scale for toxicity-

Results and Discussion

Weed flora

A total of forty-eight initial weed species were recorded at the commencement of the study. Of these, thirty were perennial and eighteen annual. Twenty-five families were dicots species while three families were monocots species. Although dicots dominated the field, the three families of the monocots were Poaceae, Commelinaceae and Cyperaceae (Table 1).

Weed control rating on individual weed species

Glyphosate applied at 1.5 kg a.i. ha^{-1}, glyphosate + diuron at 1.5 + 2 kg a.i. ha$^{-1,}$ glufosinate ammonium at 0.4 kg a.i. ha^{-1}, glufosinate ammonium at 0.5 kg a.i. ha^{-1} controlled 70.83% of the weed species, while 29.2 % of the weed species were either fairly or poorly controlled. Tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, glufosinate ammonium+ indaziflam at 0.4 + 0.05 kg a.i. ha^{-1} controlled 75% of individual weed species while 25% of the individual weed species present were either fairly or poorly controlled (Table 2). Consequently, 25% of both dicot. and monocot. weed species recorded were not controlled by the herbicide's treatment (Tables 1 & 2).

Difficult to control weeds

Fourteen weed species among the forty-eight weeds identified to be poorly or either not control by all the herbicide treatments were *Acanthus montanus, Alchornea cordifolia, Alchornea laxiflora, Brachiara deflexa, Cnestis ferruginea, Combretum racemosum, Commelina diffusa, Commelina Benghalensis, Euphorbia Heterophylla, Peperomia pellucid, Rauwolfia vomitora, Synelisia scabrida* and *Talinium triangulare* (Table 2).

Emerged weed species

Following herbicide treatments at the experimental plots, glyphosate applied at 1.5 kg a.i. ha^{-1} had 28 emerged weed species /m^2 with corresponding density of 44/m^2. Tank mixture of glyphosate + diuron at 1.5 + 2.0 kg a.i. ha^{-1} had 24 emerged weed species /m^2 with density of 30 /m^2. The plot treated with glufosinate ammonium at 0.4 kg a.i. ha^{-1} and glufosinate ammonium 0.5 kg a.i. ha^{-1} had number of emerged weed species of 23 and 23 /m^2 respectively and density of 64 and 62 /m^2 respectively. Furthermore, plots treated with tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i ha^{-1} and at 0.5 + 0.04 kg a.i. ha^{-1} had emerged weed species of 25 and 27 /m^2 respectively and weed density of 30 and 28 /m^2 respectively (Table 3). The weedy plot recorded the highest emerged weed species of 40 /m^2 and density of 175 /m^2 (Table 3).

Visual weed control rating

Herbicide treatments of glyphosate at 1.5 kg a.i ha^{-1}, glyphosate + diuron at 1.5 + 2.0 kg a.i. ha^{-1}, glufosinate ammonium at 0.4 kg a.i. ha^{-1}, glufosinate ammonium at 0.5 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.5 + 0.04 kg a.i. ha^{-1} were significantly different in visual weed control rating and sustained weed control of over 72% by eight weeks after treatment application. However, treatments of glyphosate + diuron at 1.5 + 2.0 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, and tank mixture of glufosinate ammonium + indaziflam at 0.5 + 0.04 kg a.i. ha^{-1} were significantly similar in activities up to 12 weeks and had weed incidence reduction of 89%, 91% and 91% respectively. At 16 weeks, weed incidence reduction in all treatments was also significantly dissimilar; and only the treatments with tank mixture glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, and glufosinate ammonium + indaziflam at 0.5 + 0.04 kg a.i. ha^{-1} had similar activities with over 74% weed incidence reduction. At 20 and 24 weeks poor weed incidence reduction was sustained in all the treatments. Glyphosate + diuron at 1.5 + 2.0 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, and tank mixture of glufosinate ammonium +

indaziflam at 0.5 + 0.04 kg a.i. ha^{-1} had similar weed incidence reduction of 52.3%, 53.7% and 53.3% at 20 weeks; and 32.7%, 32.3% and 32.3% at 24 respectively (Table 4).

Biomass weed reduction

Biomass of weed reduction was significantly different up to 24 weeks in all herbicide treatments However, glyphosate at 1.5 kg a.i. ha^{-1} reduced weed biomass over control to 163 $g{\cdot}m^{-2}$ and 241 $g{\cdot}m^{-2}$ at four weeks and 12 weeks respectively. Tank mixtures of glyphosate at 1.5 kg a.i. ha-^{1} + diuron at 2 kg a.i. ha^{-1} reduces weed biomass to 162 $g{\cdot}m^{-2}$ and 232 $g{\cdot}m^{-2}$ at four weeks and 16 weeks respectively (Table 7). Glufosinate ammonium at 0.4 kg a.i. ha-^{1} and at 0.5 kg a.i. ha-^{1} reduced weed biomass to 275 $g{\cdot}m^{-2}$ and 263 $g{\cdot}m^{-2}$ respectively at four weeks; then to 332 $g{\cdot}m^{-2}$ and 206 $g{\cdot}m^{-2}$ respectively at eight weeks. Furthermore, tank mixture of glufosinate ammonium + indaziflam at 0.4 kg a.i. ha^{-1} + 0.04 kg a.i. ha^{-1} or tank mixture of glufosinate ammonium + indaziflam at 0.5 kg a.i. ha^{-1} + 0.04 kg a.i. ha^{-1} had better weed biomass reduction of 221.7 $g{\cdot}m^{-2}$ and 225 $g{\cdot}m^{-2}$ respectively at 16 weeks after treatment (Table 5).

Weed control efficiency

Glyphosate at 1.5 kg a.i. ha^{-1} had moderate weed control efficiency of 87% and 67.2% respectively at four weeks and 16 weeks after treatment. Then, tank mixture of glyphosate + diuron at 1.5 kg a.i. ha^{-1} + 2 kg a.i. ha^{-1} had moderate and acceptably weed control efficiency with value of 87% and 78.5% respectively at four weeks and 20 weeks after treatment (Table 6). In effect, glufosinate ammonium at 0.4 kg a.i. ha^{-1} and at 0.5 kg a.i. ha^{-1} had short duration of efficacy with weed control efficiency value of 69.4% and 72% respectively at 12 weeks after treatment (Table 8). Consequently, tank mixture of glufosinate ammonium + indaziflam at 0.4 kg a. i. ha^{-1} + 0.04 kg a.i. ha^{-1} was more efficacious with value of 87% and 78.6% respectively at four weeks and 20 weeks after treatment. Furthermore, tank mixture of glufosinate ammonium + indaziflam at 0.5 kg a.i. ha^{-1} + 0.04 kg a.i. ha^{-1} was very efficient and acceptably efficacious with value of 87% and 78.3% at four weeks and 20 weeks after treatment (Table 6).

Weed coverage

Among the seven treatments, only tank mixture of glyphosate + diuron at 1.5 kg a.i. ha^{-1} + 2 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.4 kg a.i. ha^{-1} + 0.04 kg a.i. ha^{-1} and tank mixture of glufosinate ammonium + indaziflam at 0.5 kg a.i. ha^{-1} + 0.04 kg a.i. ha^{-1} had acceptable weed coverage value of 14.7%, 13.3% and 13% respectively at 12 weeks after treatment (Table 7). However, glyphosate at 1.5 kg a.i. ha^{-1}, glufosinate ammonium at 0.4 kg a.i. ha^{-1} and glufosinate ammonium at 0.5 kg a.i. ha^{-1} had moderately to poor weed coverage of 37.7%, 45% and 44% respectively at 12 weeks after treatment (Table 7). Glufosinate ammonium alone had moderate weed coverage only up to eight weeks after treatment (Table 7).

Herbicide toxicity

The effect of glyphosate at 1.5 kg a.i. ha^{-1} and glyphosate + diuron at 1.5 + 2 kg a.i. ha^{-1} had toxicity class of 2 & 3 with only slight, but clear symptom of yellowing at the palm fronds tip (Table 8). The palm fronds only recovered from the herbicide's symptoms after eight weeks after herbicide application. Palms in plots treated with glufosinate ammonium at 0.4 kg a.i. ha^{-1}, glufosinate ammonium at 0.5 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.5 + 0.04 kg a.i. ha^{-1} had toxicity class 1 no symptoms of herbicide toxicity on the palm fronds (Table 8).

Weed flora

The high population of perennial weeds at the experimental site could be due to the fact that in oil palm cropping systems the soil is hardly tilled or turn over and this practice could allow for the growth of perennial weeds. The high population of dicots (83.33%) over monocots (16.7%) could be due to cultural practices/ cropping systems, cropping history, prevalent high annual rainfall of 1800 mm, fertile soil with mean pH of 5.2 and fluctuations in temperatures of between 23.5^0C to 31.7^0C within the seasons (wet and dry season) in the area. Sit *et al.* (2007) and Traoré *et al.* (2010) had previously reported dominance of dicots in oil palm field in India and Côte d' Ivoire respectively.

Weed control rating on individual weed species

The high rate of control of various weed species could be due to the broad spectrum of activities of the herbicide treatments. Glyphosate, glufosinate ammonium, diuron, indaziflam had been found previously to control broad spectrum of weeds including broad leaves and grasses in crops (Akobundu, 1987). This broad spectrum of activity of the herbicides will be very apt for the oil palm farmers because only few weeds will require farmer's intervention during the period of the herbicide's activities.

Difficult to control weeds

The weeds such as *Acanthus montanus, Alchornea cordifolia, Alchornea laxiflora, Brachiara deflexa, Cnestis ferruginea, Combretum racemosum, Commelina diffusa, Commelina Benghalensis, Euphorbia Heterophylla, Peperomia pellucid, Rauwolfia vomitora, Synelisia scabrida* and *Talinium triangulare* that were poorly controlled by the herbicide treatments could be attributed to both the morphological and physiological state of the weeds and this needs further investigation to enable the selection of appropriate herbicide in other to relief oil palm farmers of the menace posed by these weeds.

Emerged weed species

The higher density of emerged weeds from the treatment of glufosinate ammonium compared to the treatments of glyphosate + diuron or glufosinate ammonium + indaziflam could be attributed to the non residual activity of glufosinate ammonium, while diuronis is known to have soil residual activity (Akobundu, 1987) The emerged weed density from the treatment of glyphosate was lower than the density of emerged weeds from the glufosinate plot probably because of the fact that glyphosate could have some level soil residual activity. While the low density of emerged weed from treatments of glufosinate ammonium + indaziflam could be due to the soil residual activity of indaziflam in the tank mixtures.

Visual weed control rating

The effectiveness of tank mixture of glufosinate ammonium + indaziflam for a long period of weed control could have resulted from the synergies of activities of the herbicides in mixture. Glufosinate ammonium controls both annual and perennial weeds, while indaziflam has a pre-emergence control against broadleaves weeds and some grasses. Tank mixtures of herbicide for weed control have been reported previously by Akobundu (1987) to either be greater (synergistic) or reduce (antagonistic) in plant response. Synergistic responses resulting from the application of different herbicides in mixtures had previously been observed in oil palm (Ekhator *et al*., 2018a; Ekhator *et al*., 2020). This long synergy of activities of the herbicides will benefit oil palm farmers because oil palm farmers will have to concentrate on other agronomic activities such as timely harvesting of ripe fruit and application of fertilizers.

Weed biomass

The similarity in low weed weight recorded over longer duration between tank mixture of glyphosate + diuron and tank mixture of glufosinate ammonium + indaziflam is an indication that tank mixture of glufosinate ammonium + indaziflam could serve as alternative choice herbicide for weed control in oil palm. The longer weed-free period observed will enable oil palm farmers to concentrate more on other cultural practices than controlling weeds. The low weed weight recorded could have indicated minimal competition of weeds with the palms. Significant reduction in weed weight has been observed previously as the most important parameter in assessing the competitiveness for crop growth and productivity because considerable reduction in weed weight implies less competition from weed (Ramalingram *et al.*, 2013).

Weed control efficiency

The moderate effectiveness of tank mixture of glyphosate + diuron and tank mixture of glufosinate ammonium + indaziflam for a longer period could be attributed to the pre-emergence activity of diuron and indaziflam in the herbicides mixtures which could have suppressed further weed seed emergence. Ekhator *et al.* (2018a) had previously reported a similar result with tank mixture of glyphosate + metsulfuron for weed control in oil palm. The similarity in efficacy of the tank mixed herbicides over a longer period showed that tank mixture of glufosinate ammonium + indaziflam could serve as an alternative choice herbicide for long period of weed control in oil palm.

Weed coverage

The moderate weed coverage observed with glyphosate +diuron in mixture and tank mixture of glufosinate ammonium + indaziflam could have resulted from the high activities of the herbicides in mixtures. These effects could be partly due to the residual effect of the pre-emergence herbicides in the mixture. This result could have indicated minimal competition of weed with the crop. Ekhator *et al.* (2018a) had previously reported similar results with glyphosate + metsulfuron for weed control in juvenile oil palm.

Herbicide toxicity

The slight symptom observed in oil palm frond with glyphosate + diuron is an indication that oil palm farmers need to be careful of glyphosate usage and most especially its abuse. The early recovery observed with the palms frond is an indication that minimal risk will be borne by the farmers in using glyphosate or glyphosate + diuron at the recommended rate. The healthy palms observed with glufosinate ammonium or glufosinate ammonium + indziflan are indicative of the suitability of these herbicides for weed control in oil palm.

Conclusion

The result concluded that tank mixture of glyphosate + diuron at 1.5+2.0 kg a.i. ha^{-1}, tank mixture of glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1} and tank mixture of glufosinate ammonium + indaziflam at 0.5 + 0.04 kg a.i. ha^{-1} were very effective in broad spectrum of weed control in oil palm. Treatments with tank mixture of glyphosate + diuron at 1.5+2.0 kg a.i. ha^{-1}, glufosinate ammonium + indaziflam at 0.4 + 0.04 kg a.i. ha^{-1}, and glufosinate ammonium + indaziflam at 0.5 + 0.04 kg a.i. ha^{-1} sustained weed control of over 74% for a longer period of 16 weeks.

Recommendation

This study recommends tank mixture of glufosinate ammonium + indaziflam at 0.4 kg a.i. ha^{-1} + 0.04 kg a.i. ha^{-1} serves as alternative choice herbicide to glyphosate +diuron for weed control in oil palm.

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TABLE 1

Initial observed weed species in the Fields of experimentation

Weed species	*Family*	*Life cycle*	*Morphology*	
			Dicot	*Monocot.*
Acanthus montanus (Nees) T. Anders	Acanthaceae	Perennial	√	-
Ageratum conyzoides Linn	Asteraceae	Perennial	√	-
*Alchornea cordifolia*Mull.Arg.	Euphorbiaceae	Perennial	√	-
Alchornea laxiflora(Benth.) Pax& K. Hoffm	Euphorbiaceae	Perennial	√	-
Alternantherabrasiliana(L.)Kuntze	Amaranthaceae	Perennial	√	-
Amaranthus spinosus Linn.	Amaranthaceae	Annual	√	-
Aspilia africana(Pers.) C.D. Adams	Compositae	Perennial	√	-
Brachiaria deflexa (Schumach.) C.E. Hubbard	Poaceae	Annual	-	√
Chromolaena odorata(L.) R.M. King & Robinson	Asteraceae	Perennial	√	-
Cleome viscosa L.	Capperaraceae	Annual	√	-
Cnestis ferruginea DC	Connaraceae	Perennial	√	-
*Combretum racemosum*P. Beauv	Combretaceae	perennial	√	-
Commelina difusa Burn f. Subsp.diffusa J.K Morton	Commelinaceae	Perennial	-	√
Commelina benghalensis L.	Commelinaceae	Perennial	-	√
Corhorusolitorius L.	Malvaceae	Perennial	√	-
Crassocephalum crepidoides(Benth) S.Moore	Asteraceae	Annual	√	-
Cyperus esculentus Linn	Cyperaceae	perennial	-	√
Cyperus rotundus Linn	Cyperaceae	Perennial	-	√
*Diodianscandens*Sw	Rubiaceae	Perennial	√	-
Dissotis berecta(Guill.&Perr.)	Melastomataceae	Perennial	√	-
Eleusine indica Gaertn	Poaceae	Annual	-	√
Erigeron floribundus H.B.& K.	Asteraceae	Annual	√	-
Euphorbia heterophylla Linn	Euphorbiaceae	Annual	√	-
Euphorbia hirta Linn	Euphorbiaceae	Annual	√	-
Fleurya aestuans(Linn.) ex Miq.	Urticaceae	Annual	√	-
Heliotropiumindicum Linn	Boraginaceae	Annual	√	-
*Hyptis lanceolata*Poir.	Lamiaceae	Annual	√	-
*Hyptissuaveolens*Poit.	Lamiaceae	Annual	√	-
Ipomea asarifolia(Desr.) Roem. &Schult.	Convolvucaceae	Perennial	√	-
Ipomea involucrate P. Beauv.	Convolvucaceae	Perennial	√	-
Melanthera scandens(Schum. &Thonn.) Roberty	Asteraceae	Perennial	√	-
Mitracarpus villosus(Sw.)	Rubiaceae	Annual	√	-
Momordica charantia Linn	Cucubitaceae	Perennial	√	-
Panicum maximum (Jacq.) R.D.Webster.	Poaceae	Perennial	-	√
Pennisetum polystacchion Rich.	Poaceae	Annual	-	√
Peperomia pellucida(Linn) H.B. & K.	Piperaceae	Annual	√	-
*Phyllantus amarus*Schum. &Thonn.	Euphorbiaceae	Annual	√	-
Physalis angulata Linn	Solanaceae	Annual	√	-
Piper umbellatum Linn	Piperaceae	Perennial	√	-
Rauwolfia vomitoria Afzel	Apocynaceae	Perennial	√	-
Scoparia dulcis Linn	Plantaginaceae	Perennial	√	-
*Sida acuta*Burm f.	Malvace	Perennial	√	-

TABLE 1 *Continued.*

Weed species	*Family*	*Life cycle*	*Morphology* Dicot.	Monocot.
Solanum torvum L.	Solanaceae	Perennial	√	-
Solanium nigra Swartz	Solanaceae	Perennial	√	-
*Synclisia scabrida*Miers ex. Oliv.	Menispermaceae	Perennial	√	-
*Synedrella nodiflora*Gaertn	Asteraceae	Annual	√	-
Talinium triangulare(Jacq.) Willd.	Portulacaceae	Perennial	√	-
Tabernaemontana Africana Hook	Apocynaceae	Perennial	√	-

TABLE 2

Effect of herbicide treatment of control of individual weed species

	Glyphosate at 1.5 kg a.i. ha-1		*Glyphosate + diuron at 1.5 +2 a.i. ha-1*		*Glufosinate ammonium at 0.4 kg a.i ha-1*		*Glufosinate ammonium at 0.5 kg a.i ha-1*		*Glufosinate ammonium at 0.5 + indaziflam at 0.4 +0.4 kga.i ha-1*		*Glufosinate ammonium at 0.5 + indaziflam at 0.4 +0.4 kga.i ha-1*	
Weed species	*% control*	*Exegesis*	*% control*	*Exegesis*	*% control*	*Exegesis*	*% control*	*Exegesis*	*% control*	*Exegesis*	*% control*	*Exegesis*
Acanthus montanus	10	No control	10	No effect	10	No effect	10	No effect	10	No effect	10	No effect
Ageratus conyzoides	90	Good	95	Good	70	Moderate	70	Moderate	75	Moderate	73	Moderate
Alchornea cordifolia	30	Poor	50	Weediness	10	No effect	10	No effect	10	No effect	10	No effect
Alchornea laxiflora	30	Poor	50	Weediness	10	No effect	10	No effect	10	No effect	10	No effect
Alternanthera brasiliana	100	Perfect	100	Perfect	85	Acceptable	85	Acceptable	85	Acceptable	85	Acceptable
Amaranthus spinosus	100	Perfect	100	Perfect	70	Moderate	70	Moderate	70	Moderate	70	Moderate
Aspilia Africana	100	Perfect	100	Perfect	85	Acceptable	85	Acceptable	90	Good	90	Good
Brachiaria deflexa	50	Weediness	60	Weediness	50	weediness	50	Weediness	70	Moderate	70	Moderate
Chromolaena odorata	70	Moderate	70	Moderate	70	Moderate	70	Moderate	85	Acceptable	85	acceptable
Cleome viscosa	80	Acceptable	100	Perfect	70	Moderate	70	Moderate	70	Moderate	70	Moderate
Cnestis ferruginea	40	Poor	40	Poor	20	Little effect	20	Little effect	30	Poor	30	Poor
Combretum racemosum	50	Weediness	50	Weediness	10	No control	10	No control	10	No control	10	No control
Commelina difusa	20	Little effect	30	Poor	20	Little effect	20	Little effect	20	Little effect	20	Little effect
Commelina benghalensis	20	Little effect	20	Little effect	20	Little effect	20	Little effect	20	Little effect	20	Little effect
Corhorus olitorius	90	Good	100	Perfect	75	Moderate	75	Moderate	85	Acceptable	85	Acceptable
Crassocephalum crepidoides	80	Acceptable	100	Perfect	70	Moderate	70	Moderate	85	Acceptable	85	Acceptable
Cyperus esculentus	90	Good	100	Perfect	70	Moderate	70	Moderate	70	Moderate	70	Moderate
Cyperus rotundus	90	Good	98	Perfect	70	Moderate	70	Moderate	85	Moderate	70	Moderate

Diodia scandens	98	Perfect	100	Perfect	70	Moderate	70	Mod-erate	85	Accept-able	85	accept-able
Dissotis erecta	90	Good	100	Perfect	70	Moderate	70	Mod-erate	70	Moder-ate	70	Moderate
Eleusine indica	90	Good	100	Perfect	85	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Erigeron flori-bundus	90	Good	100	Perfect	75	Moderate	75	Mod-erate	75	Moder-ate	75	Moderate
Euphorbia hetero-phylla	20	Little effect	20	Little effect	10	No effect	10	No effect	10	No effect	10	No effect
Euphorbia hirta	100	Perfect	100	Perfect	85	Acceptable	83	Ac-cept-able	83	Accept-able	83	Accept-able
Fleurya aestuans	100	Perfect	100	Perfect	85	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Heliotropium indicum	60	Weedi-ness	62	Weediness	40	Poor	40	Poor	40	Poor	40	Poor
Hyptis lanceolata	100	Perfect	100	Perfect	70	Moderate	72	Mod-erate	72	Moder-ate	72	Moderate
Hyptis suaveolens	100	Perfect	100	Perfect	70	Moderate	70	Mod-erate	70	Moder-ate	70	Moderate
Ipomea asarifolia	80	Accept-able	100	Perfect	70	Moderate	73	Mod-erate	73	Moder-ate	73	Moderate
Impomea invo-lucrate	85	Accept-able	100	Perfect	85	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Melanthera scandens	85	Accept-able	100	Perfect	70	Moderate	70	Mod-erate	70	Moder-ate	70	Moderate
Mitracarpus villosus	75	Moder-ate	95	Good	70	Moderate	75	Mod-erate	75	Moder-ate	75	Moderate
Momordica charantia	100	Perfect	100	Perfect	85	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Panicum max-imum	100	Perfect	100	Perfect	80	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Pennisetum polystcchion	100	Perfect	100	Perfect	80	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Peperomia pellucida	45	Weedi-ness	60	Weediness	50	Weediness	50	Weed-iness	50	Weedi-ness	50	Weedi-ness
Phyllantus amarus	80	Accept-able	95	Good	85	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Physali angulate	75	Moder-ate	95	Good	85	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Piper umbellatum	100	Perfect	100	Perfect	70	Moderate	70	Mod-erate	70	Moder-ate	70	Moderate
Rauwolfia vomitoria	10	No control	15	Little effect	65	Moderate	65	Mod-erate	63	Moder-ate	67	Moderate
Scoparia dulcis	75	Moder-ate	85	Acceptable	85	Acceptable	85	Ac-cept-able	85	Accept-able	85	Accept-able
Sida acuta	65	Moder-ate	65	Moderate	50	Weediness	50	Weed-iness	50	Weedi-ness	50	Weedi-ness
Solanum torvum	97	Perfect	100	Perfect	65	Moderate	65	Mod-erate	65	Moder-ate	65	Moderate

TABLE 2 *continued*

Weed species	*Glyphosate at 1.5 kg a.i. ha^{-1}*		*Glyphosate + diuron at 1.5 +2 a.i. ha^{-1}*		*Glufosinate ammonium at 0.4 kg a.i ha^{-1}*		*Glufosinate ammonium at 0.5 kg a.i ha^{-1}*		*Glufosinate ammonium at 0.5 + indaziflam at 0.4 +0.4 kga.i ha^{-1}*		*Glufosinate ammonium at 0.5 + indaziflam at 0.4 +0.4 kga.i ha^{-1}*	
	% control	*Exegesis*	*% control*	*Exegesis*	*% control*	*Exegesis*	*% control*	*Exegesis*	*% control*	*Exegesis*	*% control*	*Exegesis*
Solanium nigra	95	Good	95	Good	65	Moderate	65	Moderate	65	Moderate	65	Moderate
Synclisia scabrida	35	Poor	32	Poor	35	Poor	35	Poor	35	Poor	35	Poor
Synedrella nodiflora	90	Good	90	Good	70	Moderate	70	Moderate	70	Moderate	70	Moderate
Talinium triangulare	20	Little effect	20	Little effect	20	Little effect	20	Little effect	20	Little effect	20	Little effect
Tabernaemontana africana	10	No effect	20	Little effect	95	Good	100	Perfect	100	Perfect	100	Perfect

TABLE 3

Emerged weed species within the 24 weeks of data collection after herbicide treatments

Treatments	*Rate (kg a.i. ha^{-1})*	*Emerged weed species (m^{-2})*	*Density of emerged weed species /m^2*
Glyphosate	1.5	*Aspilia Africana, Brachiaria deflexa , Cleome viscose, Cnestis ferruginea, Combretum racemosum, Commelina difusa, Crassocephalum crepidoides, Corhorus olitorius, Cyperus esculentus, Cyperus rotundus, Alternanthera brasiliana, Amaranthus spinosus, Euphorbia hirta, Erigeron floribundus, Euphorbia heterophylla, Eleusine indica, Dissotis erecta, Alchornea cordifolia, Alchornea laxiflora, Panicum maximum, Peperomia pellucida, Phyllantus amarus, Pennisetum polystcchion, Talinium triangulare, Synclisia scabrida, Synedrella nodiflora, Tabernaemontana Africana, Sida acuta*	2, 1, 1, 1, 2, 2, 1, 1, 3, 2, 3, 2, 2, 1,1, 1, 1, 1, 1, 2, 2, 1, 1, 3,1, 1, 3, 3,. (44)
Glyphosate + Diuron	1.5 + 2	*Acanthus montanus, Alchornea cordifolia, Alchornea laxiflora, Aspilia Africana, Brachiaria deflexa, Chromolaena odorata, Cyperus esculentus, Cyperus rotundus, Eleusine indica, Euphorbia heterophylla, Fleurya aestuans, Rauwolfia vomitoria, Scoparia dulcis, Sida acuta, Heliotropium indicum, Cnestis ferruginea, Combretum racemosum, Commelina difusa, Melanthera scandens, Synclisia scabrida, Talinium triangulare, Tabernaemontana Africana, Momordica charantia, Peperomia pellucida*	1 2, 1, 2,1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 2, 1, 1,1, 2, 1, 1, 2. (30)
Glufosinate ammonium	0.4	*Centrosema pubescens, Thamatococucus daniellii, icacina trichantha, Solanium nigra, Synclisia scabrida, Solanum torvum, Fleurya aestuans, Acanthus montanus, Ageratus conyzoides, Alchornea cordifolia, Alchornea laxiflora, Combretum racemosum, Commelina difusa, Commelina benghalensis, Aspilia Africana, Brachiaria deflexa, Cleome viscosa, Cnestis ferruginea, Erigeron floribundus, Euphorbia heterophylla, Euphorbia hirta, Panicum maximum, Pennisetum polystcchion.*	3, 3, 3, 2, 2, 1, 5, 2, 4, 1, 2, 2, 2, 2, 8, 1, 2, 1, 2, 2, 6, 6, 2 (64)

TABLE 3 *continued*

Glufosinate ammonium	0.4	*Centrosema pubescens, Thamatococucus daniellii, icacina trichantha, Solanium nigra, Synclisia scabrida, Solanum torvum, Fleurya aestuans, Acanthus montanus, Ageratus conyzoides, Alchornea cordifolia, Alchornea laxiflora, Combretum racemosum, Commelina difusa, Commelina benghalensis, Aspilia Africana, Brachiaria deflexa, Cleome viscosa, Cnestis ferruginea, Erigeron floribundus, Euphorbia heterophylla, Euphorbia hirta, Panicum maximum, Pennisetum polystcchion.*	5, 2,3,2, 4,3, 4, 1, 3, 6, 1, 3, 3, 2, 7, 3, 1, 1, 1, 1, 3, 3, 2. (62)
Glufosinate ammonium + indaziflam	0.4 + 0.04	*Centrosema pubescens, Thamatococucus daniellii, icacina trichantha, Solanium nigra, Synclisia scabrida, Solanum torvum, Fleurya aestuans, Acanthus montanus, Alchornea cordifolia, Alchornea laxiflora, Combretum racemosum, Commelina difusa, Commelina benghalensis, Brachiaria deflexa, Cleome viscosa, Cnestis ferruginea, Erigeron floribundus, Euphorbia heterophylla, Euphorbia hirta, Panicum maximum, Pennisetum polystcchion, Rauwolfia vomitoria., Piper umbellatum, Melanthera scandens, Erigeron floribundus*	2, 1, 1, 1, 1,, 1, 2, 1, 1, 1, 2, 1, 1, 2, 1, 1, 1,1, 1, 1, 1, 1, 1,2, 1 30)
Glufosinate ammonium + indaziflam	0.4 + 0.05	*Thamatococucus daniellii, icacina trichantha, Solanium nigra, Synclisia scabrida, Solanum torvum, Fleurya aestuans, Acanthus montanus, Alchornea cordifolia, Alchornea laxiflora, Combretum racemosum, Commelina difusa, Commelina benghalensis, Brachiaria deflexa, Cleome viscosa, Cnestis ferruginea, Erigeron floribundus, Euphorbia heterophylla, Euphorbia hirta, Panicum maximum, Pennisetum polystcchion, Rauwolfia vomitoria, Solanium nigra, Piper umbellatum, Mitracarpus villosus, Euphorbia heterophylla, Melanthera scandens, Mitracarpus villosus.*	1, 2,1, 1, 1, 1 1, 1, 1, 2, 2, 1, 1, 1, 1, 1 ´, 2, 1, 1, 1, 1, 1, 1, 1, (28)
Weedy plot	0.0	*Acanthus montanus, Ageratus conyzoides, Alchornea cordifolia, Alternanthera brasiliana, Amaranthus spinosus, Aspilia Africana, Brachiaria deflexa, Chromolaena odorata, Cnestis ferruginea, Combretum racemosum, Commelina difusa, Crassocephalum crepidoides, Cyperus esculentus, Cyperus rotundus, Dissotis erecta, Eleusine indica, Erigeron floribundus, Euphorbia heterophylla, Euphorbia hirta, Heliotropium indicum, Hyptis lanceolata, Hyptis suaveolens, Ipomea asarifolia, Impomea involucrate, Melanthera scandens, Mitracarpus villosus, Panicum maximum, Pennisetum polystcchion, Peperomia pellucid, Phyllantus amarus, Physali angulata, Rauwolfia vomitoria, Scoparia dulcis, Sida acuta, Solanum torvum, Solanium nigra, Synclisia scabrida, Synedrella nodiflora, Talinium triangulare, Tabernaemontana Africana.*	2,6, 1, 4, 5,8, 3, 4, 2, 4, 5, 3, 6, 6, 4, 5, 6, 2, 7, 4, 5, 3, 4, 4,3, 8, 4, 6, 3,3, 4, 4, 2, 4, 3, 2, 5, 2, 3, 6. (175)

TABLE 4

Efficacy of herbicide treatments on weed control in oil palm.

Treatment	Kg a.i. ha $^{-1}$	Weeks after treatment 4	8	12	16	20	24
		Visual weed control rating %					
Control	0.0	0.0d	0.0d	0.0	0.0g	0.0d	0.0d
Glyphosate	1.5	85.0b	86.7b	73.0b	45.3d	25.0b	12.7bc
Glyphosate + Diuron	1.5 + 2	88.0a	90.7a	89.0a	68.7c	52.3a	32.7a
Glufosinate ammonium	0.4	80.7c	72.7c	57.3c	32.3e	21.7c	10.7c
Glufosinate ammonium	0.5	80.7c	72.0c	57.3c	36.3f	26.0b	14.0b
Glufosinate ammoium + indaziflam (tank mix)	0.4+0.04	87.7a	90.7a	91.0a	75.7a	53.7a	32.3a
Glufosinate ammonium + indaziflam (tank mix)	0.5 +0.04	86.3ab	91.0a	91.0a	74.0a	53.3a	32.3a
S.E		0.7	1.1	1.4	1.3	1.4	1.0
CV		1.7	1.9	2.6	3.4	5.1	6.6

TABLE 5

Efficacy of herbicide treatments on weed biomass suppression in oil palm

Treatment	Kg a.i. ha $^{-1}$	Weeks after treatment 4	8	12	16	20	24
		Biomass of weed regrowth (g m $^{-2}$)					
Control	0.0	1240.0a	1333.0a	1586.7a	1646.7a	1703.3a	1733.3a
Glyphosate	1.5	163.0c	137c	241.0c	580.3d	896.0c	1224.7c
Glyphosate + Diuron	1.5 + 2	162.0c	151c	160.3d	232.3e	367.0d	677.7d
Glufosinate ammonium	0.4	275.0b	332b	485.3b	736.7b	910.7b	1633.0b
Glufosinate ammonium	0.5	263.0b	206b	444.7b	709.3c	897.7c	1194.3c
Glufosiante ammonium + indaziflam (tank mix)	0.4+0.04	159.0c	149c	154.3d	221.7e	365.3d	714.3d
Glufosinate ammonium + indaziflam (tank mix)	0.5 +0.04	159.0c	149c	154.0d	225.0e	369.0d	708.7d
S.E		41.4	63.9	22.49	5.61	5.8	20.83
CV		14.7	22.3	6.0	1.1	0.9	2.3

TABLE 6

Effectiveness of herbicide treatments on weed control in oil palm.

Treatment	*Kg a.i. ha $^{-1}$*	*Weeks after treatment* 4	8	12	16	20	24
		Weed control efficiency %					
Control	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glyphosate	1.5	87.0	90.0	85.0	67.2	47.4	29.3
Glyphosate + Diuron	1.5 + 2	87.0	89.0	90.0	86.9	78.5	60.9
Glufosinate ammonium	0.4	78.0	75.0	69.4	55.3	46.5	5.7
Glufosinate ammonium	0.5	78.0	85.0	72.0	56.9	47.3	31.1
Glufosinate ammonium + indaziflam (tank mix)	0.4+0.04	87.0	88.0	90.0	86.5	78.6	58.8
Glufosinate ammonium + indaziflam (tank mix)	0.5 +0.04	87.0	88.0	90.0	86.3	78.3	59.1

TABLE 7

Effect of herbicide treatments on weed coverage in oil palm.

Treatment	*Kg a.i. ha $^{-1}$*	*Weeks after treatment* 4	8	12	16	20	24
		Weed coverage (%)					
Control	0.0	100.0a	100.0a	100.0a	100.0a	100.0a	100.0a
Glyphosate	1.5	16.7b	14.7c	37.7c	66.3b	74.0c	87.3b
Glyphosate + Diuron	1.5 + 2	13.7e	12.7c	14.7d	45.3d	58.7d	69.3d
Glufosinate ammo-nium	0.4	19.0b	29.7b	45.0b	67.7c	81.3b	91.7b
Glufosinate ammo-nium	0.5	18.0c	30.0b	44.0b	61.0c	80.7b	72.7c
Glufosinate ammo-niaum + indaziflam (tank mix)	0.4+0.04	15.3d	12.0c	13.3d	47.7d	59.0d	71.3c
Glufosinate ammo-niaum + indaziflam (tank mix)	0.5 +0.04	13.7e	13.3c	13.0d	44.7d	61.0d	74.3c
S.E		0.6	1.0	1.7	2.8	2.0	9.2
CV		2.5	4.2	5.5	5.7	3.4	13.9

TABLE 8

Effect of herbicides treatments to oil palm fronds

Treatment	*Kg a.i. ha* $^{-1}$	*Toxicity*					
		Weeks after treatment					
		4	*8*	*12*	*16*	*20*	*24*
Herbicide free plot (control)	0.0	1	1	1	1	1	1
Glyphosate	1.5	3	2	1	1	1	1
Glyphosate + Diuron	1.5 + 2	2	2	1	1	1	1
Glufosinate ammonium	0.4	1	1	1	1	1	1
Glufosinate ammonium	0.5	1	1	1	1	1	1
Glufosinate ammonium + indaziflam (Tank mix)	0.5+0.04	1	1	1	1	1	1
Glufosinate ammonium + indaziflam (Tank mix)	0.5+0.05	1	1	1	1	1	1

APPENDIX I

Scale of evaluation of herbicide treatments' effectiveness according to the European Weeds Research Council (EWRC)

Note	*Coverage rate (%)*	*Effectiveness rate (%)*	*Interpretation*
1	99	1	No effectiveness
2	93	7	Very low effectiveness
3	85	15	Little marked effectiveness
4	70	30	Poor effectiveness
5	50	50	Weediness50% decrease
6	30	70	Moderate effectiveness
7	15	85	Acceptable effectiveness
8	7	93	Good effectiveness
9	0	100	Perfect effectiveness

Source: Adapted from Mathieu & Marnotte, (2000)

APPENDIX II

European Weeds Research Society –scale for visual rating of herbicide toxicity

Class	*Symptoms of damage*
1	No damage/healthy plant
2	Very slight symptoms, weak suppression
3	Slight but clearly visible symptoms
4	Severe symptoms(e.gchlorosis) which do not lead to a negative effect on yield
5	Thinning, severe chlorosis or suppression; yield reduction expected
6	Severe damage up to complete destruction
7	Severe damage up to complete destruction
8	Severe damage up to complete destruction
9	Severe damage up to complete destruction

Source: Adapted from Ekhator *et al.* (2018)